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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01S 5/14, 1/68	A1	(11) International Publication Number: WO 98/57190 (43) International Publication Date: 17 December 1998 (17.12.98)

(21) International Application Number: PCT/US98/11985

(22) International Filing Date: 10 June 1998 (10.06.98)

(30) Priority Data:
08/872,257 10 June 1997 (10.06.97) US

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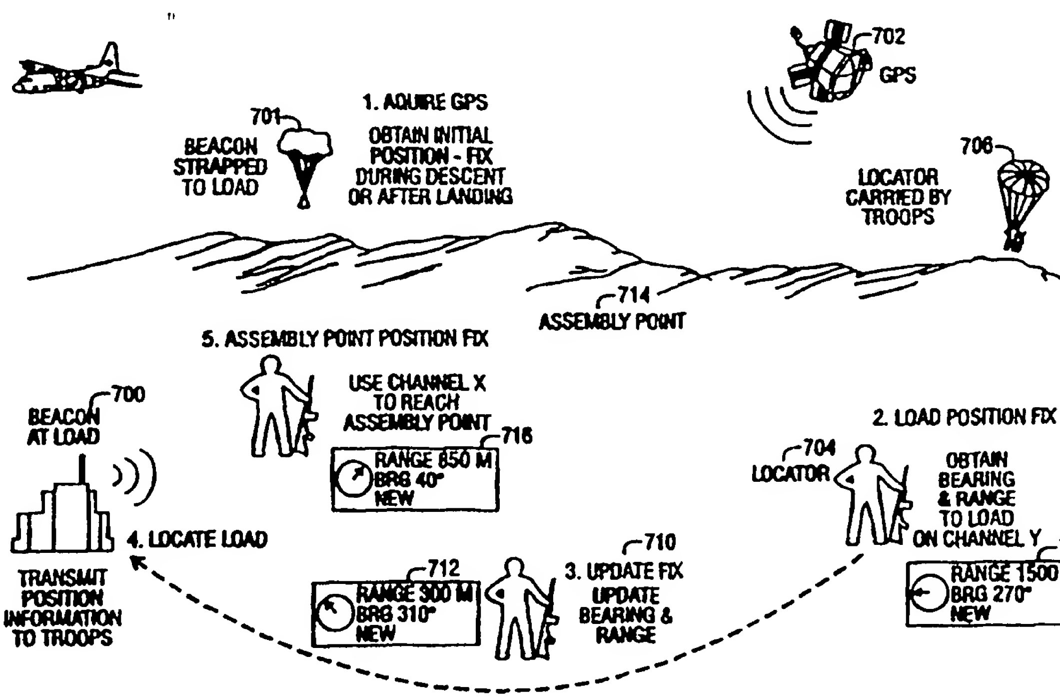
(81) Designated States: AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD AND APPARATUS FOR GLOBAL POSITIONING SYSTEM BASED COOPERATIVE LOCATION SYSTEM



(57) Abstract

A cooperative location system for use with a Global Positioning System ("GPS"). The system includes a beacon that receives GPS signals and transmits GPS data representing the location of the beacon to a remote locator. The locator receives the beacon's GPS data from the beacon. Based on the beacon's GPS data, a reference direction provided by a compass, and the locator's own GPS data, the locator calculates range and direction information to the beacon.

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DESCRIPTION

METHOD AND APPARATUS FOR GLOBAL POSITIONING SYSTEM BASED COOPERATIVE LOCATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a location system for locating a cooperative beacon. More particularly, it concerns a location system based on Global Positioning System ("GPS") technology that permits accurate range and direction detection of a cooperative beacon using relative GPS ("RGPS") differential range and direction.

2. Description of Related Art

The Global Positioning System ("GPS") presently consists of a constellation of 24 satellites that continuously broadcast time and frequency data on two frequencies, L1 and L2. GPS receivers have been developed that can determine a precise location on the earth by measuring the time required for the signals of three, or preferably four or more, of the satellites to reach the location on earth. Using these measurements and triangulating, the GPS receiver's position may be calculated. The GPS receiver provides position information in the form of X, Y, and Z axes coordinates measured in meters from the center of the earth. The position information is provided using 9 significant digits (e.g., 4137958.36).

GPS provides both a commercial version of GPS data and secure versions of GPS data. The secure versions of the GPS data requires the use of classified codes provided by the United States Government to decode the data. The commercial version of GPS data, referred to as C/A ("Coarse Acquisition") code GPS, uses only the L1 frequency and does not require any decoding. However, the United States Government imposes pseudo-random errors (referred to as selective availability ("S/A") random errors) into the location data provided by the satellites. Therefore, due to this introduced error, existing C/A code GPS based navigation aids provide a low resolution direction to a fixed point on the earth, *i.e.* a waypoint, with only an approximate

range to the desired location. The Department of Defense controls the S/A random errors and determines the true accuracy of C/A commercial user GPS. The accuracy is nominally set to 300 meters spherical (3d RMS) or 100 meters horizontal (2d RMS). The classified version requiring code settings (Y-code) is much more accurate (on the order of 16 meters).

Alternatively, prior art locator systems using C/A mode GPS provide more accuracy by using differential GPS ("DGPS") techniques. These existing C/A mode DGPS based systems require a surveyed base site capable of calculating the introduced error from the C/A mode GPS data. The surveyed base site transmits the calculated error information to the locator. From its own C/A mode GPS data and the calculated error transmitted from the surveyed base site, the locator can correct for any introduced S/A error.

Existing GPS based locator systems further define their bearing information based on movement along a baseline. Until the user moves, however, there is no way for the user to determine the direction that they are going because GPS provides only an instantaneous position. Therefore, two subsequent positions are required to define direction.

Thus, a need has arisen for a system capable of accurately locating a beacon from a locator without using any external aids or surveys. In addition, a need has arisen for a locator in which no motion is required to determine range or bearing information. Further, a need has arisen for a cooperative location system operating at low (truncated) data rates in order to permit efficient transmission of information between a beacon and a locator.

SUMMARY OF THE INVENTION

The invention is a method and apparatus for providing the accurate direction and range from a locator to a cooperative beacon by using GPS positions at both the beacon and locator, with a data links between the units. This invention substantially eliminates or reduces the disadvantages and problems associated with previously developed location systems.

For example, in one embodiment of the invention, a beacon is positioned at a first point on the earth and a locator is positioned at a second point on the earth. The beacon comprises a GPS receiver for receiving GPS data representing the first point on the earth. The beacon also includes a transmitter for transmitting this data representing the first point on the earth to the

locator. The locator includes a receiver operable to receive the beacon's first set of GPS data representing the location of the beacon. The locator also includes a GPS receiver for receiving a second set of data representing the location of the locator. In order to provide a reference direction for the locator, a compass is included with the locator. Finally, the locator includes a processor for calculating range in direction information to the beacon based on the first set of GPS data, second set of GPS data, and the referenced direction provided by the compass. By providing a reference direction, no movement is required to determine bearing or range information.

The invention is preferably implemented using RF at low band VHF. The use of RF at low band VHF provides some degree of terrain following to reduce the dependence on line of sight transmissions, such as microwaves or light waves, which can either be blocked by foliage or other obstructions.

In another embodiment of the invention, the beacon transmits truncated data to the locator. This truncated data is formed by retaining the least significant digits of the GPS data that are lower in order than the most significant digits of two times a specified maximum range of operation around the beacon. By truncating the data, the present invention significantly reduces the amount of data that must be transmitted from the beacon to the locator.

According to another embodiment of the invention, a method is provided for determining the location and direction of a beacon by a locator. The locator receives a first set of GPS data representing the beacon's location on the earth. The locator also receives a second set of GPS data representing its location on the earth. Next, a reference direction is provided and the locator calculates the range and direction information of the beacon from the first and second sets of GPS data and the reference direction. Preferably, the first set of GPS data representing the location of a beacon is truncated data.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood

by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

FIG. 1 is an exemplary embodiment of a beacon of the present invention.

FIG. 2 is a functional diagram of an exemplary beacon of the present invention.

FIG. 3 is a block diagram of an exemplary beacon of the present invention.

FIG. 4 is an exemplary embodiment of a locator of the present invention.

FIG. 5 is a functional diagram of an exemplary locator of the present invention.

FIG. 6 is a block diagram of an exemplary locator of the present invention.

FIG. 7 illustrates the use of the cooperative location system of the present invention.

FIG. 8 is a chart of the GPS accuracy for various GPS locator systems, including the relative locator system of the present invention.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The invention encompasses using GPS and an electronic magnetic compass for relative navigation (RGPS) without external aids or site surveys. It also includes a method of performing RGPS at very low (truncated) data rates.

The invention is designed, and has been operationally demonstrated, to be comprised of one or more beacons, and one or more locators that in concert provide the locator both the range and direction to the cooperative beacons on a given data transmission channel. In operation, a beacon determines its GPS position and the identification of the satellites that were used in the calculation, and compresses and transmits that data over a non-line of sight RF data link to the locator. A locator independently determines its GPS position and the satellites used in the position calculation, and compares that data to the received beacon position and satellite identification. The difference between the beacon and locator position data provides sufficiently accurate range and bearing information at long ranges (from several kilometers down to tenths of kilometers) despite S/A random errors. At short ranges (within tenths of a

kilometer), S/A random errors may affect the accuracy of the system. However, by taking the difference of the recent position data of the beacon and locator, the effect of the S/A induced position errors are canceled out when using the same set of satellites. Further, by comparing its satellite identification information with the satellite identification numbers sent by the beacon, the locator can indicate a "Good" solution when the same set of satellites is being used for both sets of calculations, and therefore the most accuracy is expected. Otherwise, the locator can indicate that a different set of satellites has been used and the solution is "Bad," *i.e.*, the S/A induced errors for the different sets of satellites affects the locators range and bearing information.

Using the difference between the beacon and locator positions provides the range between the two units and an absolute bearing in space. By using the north reference from the electronic compass built into each locator, the absolute pointing angle can be referenced to the local pointing angle at each operating unit, showing each operator the direction that they need to go to reach the beacon. This accurate dual range and bearing presentation permits an operator to assess when and how obstacles can be effectively skirted when attempting to locate a beacon.

In addition, different beacons can be operated simultaneously on different channels. Each locator can be tuned to the particular channel that corresponds to the beacon at a first or second destination. Once that position is located, the locator can be set to a new channel, and the process repeated for the new location (see FIG. 9).

The following examples are included to demonstrate exemplary embodiments of the invention. Exemplary embodiments of the present invention are illustrated with like numerals being used to refer to like and corresponding parts of the various drawings. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventors to function well in the practice of the invention. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

In addition, the present invention is illustrated with examples demonstrating the usage of the cooperative location system on land. It should be understood, however, that the present

invention could be used for air or sea based operations. In fact, airborne and seaborne usage present less stringent requirements than land based operation of one embodiment of the invention since airborne usage during level flight does not randomly occult satellites in a constellation and seaborne usage does not need to account for large changes in elevation from the baseline to field operation.

FIG. 1 is an exemplary embodiment of a beacon according to the present invention. The beacon **2** includes a GPS antenna **4** and GPS receiver **6** (see FIG. 2) for receiving GPS signals representing the location of the beacon 2. From these GPS signals, the beacon 2 derives its GPS data, including its position data and the identification of the satellites used to determine this data. Within the beacon 2, a data transmitter **10** (see FIG. 2) sends this GPS data *via* antenna **12** to an external locator. In an exemplary embodiment, data is transmitted between the beacon and locator using VHF RF transmission. Prior to transmission, the data is modulated using BPSK modulation. Further, the data may be encoded using any available coding techniques such as PN coding. It should be understood, however, that the modulation and encoding of data prior to transmission is not limited to the methods disclosed in the specification. Alternative methods of modulation and encoding can be used without departing from the spirit and scope of the invention as defined in the claims.

A keypad **14** permits entry of commands to the beacon 2. An LCD display **16** provides status information concerning the beacon 2. In an exemplary embodiment, the display **16** provides information such as the beacon's GPS position data and satellite identification information. Further, the display **16** may also display the radio frequency or channel that the beacon uses to transmit data to a locator.

The beacon **2** is turned on and off by power switch **18**. In an embodiment of the invention, power control terminals **8a** and **8b** are provided to allow the beacon **2** to be placed into a "sleep" mode. The terminals may be connected via a wire to prevent current from flowing to the internal components of the beacon **2**, thereby saving battery power. Once the wire is disconnected, as by the deployment of a parachute or other means, current may flow from the beacon's battery **20** to its internal components.

FIG. 2 depicts a functional block diagram of an exemplary beacon **2**. GPS signals are received at a GPS receiver **6** *via* an antenna **4**. The GPS receiver **6** passes the GPS data, including its GPS position and satellite identification information, to a processor **22**. Processor **22** includes a keypad **14** for an operator to enter data and control operation of the beacon **2**. A display **16** is included to provide status and location information to the operator. The processor **22** communicates with a datalink transmitter **10** for transmitting GPS data via antenna **12** to a remote locator. The beacon includes a battery **20** to supply the power to operate the beacon. The battery **20** may be a lithium-type battery or any other suitable battery.

FIG. 3 is a block diagram of an exemplary beacon of the present invention. GPS signals are received at a GPS receiver **6** via an antenna **4**. The beacon **2** then derives its GPS position data and satellite identification information and transmits the data to a locator. In this exemplary embodiment, data is transmitted using standard spread spectrum techniques and frequency hopping techniques well-known in the art. However, it should be understood that transmission can be performed using any well known transmission and coding techniques. For additional security from eavesdropping, data may be encrypted prior to transmission using standard encryption algorithms. Truncating the data also adds a degree of security since an unauthorized receiver outside the intended range of the device will be unable to properly reconstruct the true location of the beacon.

The GPS receiver **6** interfaces to the processor **22** through a GPS receiver interface **302**. The GPS receiver **6** provides the processor **22** with GPS data in ASCII format. The GPS data is transferred to the Beacon Position/Time Data Format Module **304** of the processor **22** by an RS-232 or RS-422 connection **306**. From this data, the processor **22** formats the GPS data in modules **308** and **310** and displays the data through a display interface **312** of processor **22** on display **16**. The display format is selected by an operator at the keypad **14**.

The keypad **14** also permits an operator to control other operations of the beacon **2**. Commands entered at keypad **14** are provided to the processor **22** through a keyboard interface **316**. For example, an operator can enter the channel that the beacon **2** will transmit on. This information is received by the processor **22** through keyboard interface **316** and passed on to a channel select module **318** of the processor **22**. The channel select module **318** passes this

information on to the display/select format module **310**. Thus, the channel select information can be displayed at display **16** through the display interface **312**.

The channel select module **318** also provides the channel information to a 50 channel PN (pseudo-random number) code memory **320**. The PN code corresponding to the selected channel is placed in PN code format in module **330** and provided to the datalink transmitter **10**. An exemplary embodiment provides for 50 channels for the beacon **2** to transmit on. The corresponding locator must be programmed to the same channel in order to receive the beacon's transmitted data.

The channel select module **318** may also provide the channel select information to a frequency hopping sequential memory **326**. Once again, an exemplary embodiment provides for a 50 frequency hopping sequential memory. The processor includes a synthesizer control **328** for controlling the frequency synthesizer **340**. The synthesizer control **328** receives a signal from the frequency hop clock **324** and the frequency hop memory **326**. From these signals the synthesizer control **328** controls the frequency the synthesizer **340** transmits on. Once again, the locator must be synchronized with the beacon in order to receive the beacon's transmitted position data during frequency hopping.

To maintain synchronization during frequency hopping, a clock generator **322** receives time data from the GPS receiver **6**. As described below, the locator also receives time data from its GPS receiver. Based on this information, the beacon and locator can remain synchronized during frequency hopping.

It should be understood that use of frequency hopping is merely exemplary. The present invention can be operated using only PN coding without using frequency hopping techniques. In an embodiment of the invention using only PN coding, channel select module **318** indicates the single frequency to transmit on. Subsequently, synthesizer control **328** controls the transmit frequency of the synthesizer **340**.

The processor **22** of the present invention provides the following data to data transmitter **10:** the GPS data, a PN code, and a Synth Freq Command, which controls the frequency of the synthesizer. The GPS data is formatted by the processor **22** in the Format GPS Data Module **332**. In PN Coding Module **334**, the position data is encoded using standard PN coding

techniques. The data is modulated at the BPSK modulator **336** at the frequency controlled by the synthesizer **340.** The modulated data is amplified by VHF power amplifier **338** and transmitted via VHF Datalink antenna **12**.

Power is supplied to the beacon by a 12-volt battery **20**. Master power switch **18** controls when power is supplied to the beacon **2**. Prior to supplying power to the beacon **2**, the output of the 12-volt battery **20** is supplied to a power conditioning circuit **342** in order to provide a 12-volt and 5-volt input to the internal components of the beacon **2**.

FIG. 4 is a physical layout of an exemplary locator according to the present invention. The locator **400** includes a GPS antenna **402** and a GPS receiver **404** (shown in FIG. 5) for receiving GPS signals representing the position of the locator **400**. From these GPS signals, the locator **400** derives its GPS data, including its position data and the identification of the satellites used to determine this position. An antenna **408** is also provided for receiving GPS data transmitted from a remote beacon. In an exemplary embodiment, data is transmitted between the beacon and locator using RF transmission at VHF frequencies. The use of RF at low band VHF provides some degree of terrain following to reduce the dependence on line of sight transmissions, like microwaves or light waves (including IR) that can easily be blocked by foliage or other obstructions. It should be understood, however, that alternative methods of transmission can be used without departing from the spirit and scope of the invention as defined in the claims. Power switch **410** turns the locator **400** on and off.

The locator **400** further includes a keypad **412** that permits entry of commands to the locator **400**. An LCD display **414** provides status information concerning the locator **400** and range and bearing information to a cooperative beacon. The display **414** further provides information as to whether the beacon and locator have used the same set of satellites to calculate the range and bearing information. When the same set of satellites is used to calculate position information at the beacon and locator, any induced S/A errors are canceled out. Thus, the locator will indicate at display **414** that the solution is "Good." When a different set of satellites is used at the beacon and locator, induced errors from both sets of satellites will be cumulative. Thus, the locator will indicate at display **414** that the solution is "Bad." It should be understood, however, that a "Bad" solution may still provide sufficient accuracy at long ranges for purposes of locating a cooperative beacon despite induced S/A errors. At short

ranges (within tenths of a kilometer), however, the specific satellites used in the position solution affect the accuracy of the relative solution. Thus, it is important for an operator to realize when the locator and cooperative beacon have used different satellites to derive their GPS data.

In fact, the use of random subsets of a satellite constellation from the GPS satellite system does not merely gracefully degrade the accuracy of the remaining satellite position solution. Instead, depending on the satellites chosen, the relative solutions could actually be worse than the 100 meter S/A induced independent GPS solution errors. For that reason, the GPS receivers of the present invention are programmed to improve the probability of selecting the same satellites. The receivers are set to use the "best 4 - high 8" solution (which uses the best four satellites while tracking up to eight visible satellites) rather than the "over determined 6" (which might provide a more accurate absolute solution but must use five or six satellites), with the GPS receivers commanded to "3-D manual" (so that the solution does not randomly switch between using three or four satellites) and with slightly higher elevation mask angles than normal for better visibility above the terrain. Using such receivers increases the probability that both the beacon and the locator will see and use the same "correlated" subset of the visible satellites constellation. It should also be noted that helmet mounted GPS antennas would improve constellation visibility and hence would also increase the probability that a correlated set of satellites will be used.

FIG. 5 depicts a functional block diagram of an exemplary locator. GPS signals are received at a GPS receiver **404** *via* an antenna **402**. The GPS receiver **404** passes the GPS data to a processor **420**. Processor **420** includes a keypad **412** for entry of data and controlling operation of the locator. A display **414** is included to provide status and location information to a user. The processor **420** communicates with a datalink receiver **406**, which receives a remote beacon's position and satellite identification data via antenna **408**. The locator includes a battery **416** to supply the power to operate the locator. The battery **416** may be a lithium-type battery or any other suitable battery.

The locator further includes a compass **418** for providing a north reference. The reference data is passed on to the processor **420**. From this data, the processor **420** can calculate the pointing angle in which an operator located at a locator needs to go in order to reach the

beacon. This accurate dual range and bearing presentation permits the operator to assess when and how obstacles can be effectively skirted when attempting to locate a beacon. In an exemplary embodiment, the compass **418** is an electronic compass. However, it should be understood that alternative means for providing a reference direction could be used without departing from the scope of the invention as defined by the claims. By providing a reference direction, the present invention provides an improvement over the prior art locators that required motion to determine bearing information.

FIG. 6 is a block diagram of an exemplary locator **400** of the present invention. GPS signals are received at a GPS receiver **404** via an antenna **402**. From these GPS signals, the locator derives its GPS data, including its position data and the identification of the satellites used to determine its position. The GPS receiver interfaces to a processor **420** through a GPS receiver interface **602**. The GPS receiver **404** provides the processor **420** with its GPS data in ASCII format. The locator position/time data is transferred to the processor **420** by an RS-232 or RS-422 connection **606**.

In addition to receiving its own GPS position data, the locator **400** also receives from a beacon **2** data representing the location of the beacon 2. VHF datalink antenna **408** receives the modulated signal and provides the signal to the datalink receiver **406**. The datalink receiver **406** filters the modulated signal in filter module **608**. The filter module **608** is any standard interference rejection filter. The filter module **608** includes a standard low noise amplifier. The received signal is converted down in frequency by downconverter **610**. The synthesizer **612** is a local oscillator operating under control of the processor's synthesizer control **632**. The synthesizer **612** provides the downconverter **610** with the frequency corresponding to the channel upon which data should be received.

After downconverting, the signal is passed through an IF amplifier and filter **614**. The signal is then converted to a digital representation by an A/D converter **616**. The sampled signal is downconverted to the baseband frequency in baseband downconverter **618**. The processor provides the corresponding PN code to the datalink **406** for demodulation. The signal is then demodulated using a matched filter **620**. The resulting data is transferred to a Beacon Position/Data Format Module **634** of processor **420**.

An operator controls operation of the locator **400** through a keypad **412**. Commands entered at keypad **412** are provided to the processor **420** through a keyboard interface **646**. For example, an operator can enter the channel corresponding to the beacon **2** that the locator is attempting to locate. This information is received by the processor through keyboard interface **646** and passed on to a channel select module **648** of the processor **420**. Then, the channel select module **648** selects the corresponding PN code for that channel from 50 PN Code Memory **626**. The PN code corresponding to the selected channel is placed in PN code format **628** and provided to the datalink receiver **406**. For proper operation, the beacon and locator must be set to the same channel for transmission and reception.

The channel select module **648** may also provide the channel select information to a 50 frequency hopping sequential memory **630**. The processor includes a synthesizer control **632** for controlling the frequency synthesizer **612**. The synthesizer control **632** receives a signal from the frequency hop clock **624** and the frequency hop memory **630**. From these signals the synthesizer control **632** controls the receive frequency of the datalink receiver **406**. Once again, the locator must be synchronized with the beacon in order to receive the beacon's transmitted position data during frequency hopping. In order to maintain synchronization during frequency hopping, a clock generator **622** receives time data from GPS receiver **404**. Based on this information, the beacon and locator can remain synchronized during frequency hopping.

After demodulation of a signal from a beacon by the datalink receiver **406**, the data is provided to beacon position data format module **634** of the processor **420**. The data is formatted and transferred to the calculate direction vector module **636**. Based on the GPS data from the beacon position data format module **634** and the data received from the locator position/data format module **604**, the processor **420** calculates a direction vector that indicates the range and angle between the beacon **2** and locator **400**. A compass **418** further provides a north reference through the processor's compass interface **638**. The reference data is passed on to the processor's calculate direction display module **640**. From this data, the module **640** calculates the pointing angle, relative to north, in which an operator at a locator **400** needs to proceed in order to reach the beacon **2**. The result is formatted in display module **642** and displayed on display **414** through the display interface **644**. The display format is selected by an operator at the keypad **412**.

Power is supplied to the locator by a 6-volt battery **416**. Master power switch **410** controls when power is supplied to the locator **400**.

FIG. 7 illustrates an exemplary application of the cooperative location system of the present invention using one locator and two beacons. It should be understood, however, that the invention is not limited to this specific embodiment. Various combinations of beacons and locators may be used in the system without departing from the spirit and scope of the invention as defined by the claims.

Initially, a beacon **700** is strapped to a load **701** and placed by any of various delivery means such as an airdrop or hand deployment at a first point on the earth. The beacon **700** acquires its initial GPS data based on a signals received from a concentration of GPS satellites **702** during descent or after landing. A locator **704** is carried by an operator **706** and is placed at a second point on the earth. The locator **704** also obtains its initial GPS position data based on signals received from GPS satellites **702**. The locator **704** further obtains the initial GPS data from the beacon **700** on a first data transmission channel (shown as channel "Y"). From this data, the locator **704** obtains initial bearing and range data **708**. By using an electronic compass, the locator **704** provides a pointing angle to the beacon **700**. The bearing and range data may be displayed to the operator using the locator's display **414**. From this bearing and range data, the operator can proceed toward the load **701**.

After traversing several obstacles on his way to the load **701**, the operator **706** arrives at a new location **710**. Once at this location, the operator can use the locator **704** to update the bearing and range data to beacon **700**. Once again, the locator obtains its own GPS data based on signals received from GPS satellites **702** and the GPS data for the beacon **700** received on the first data transmission channel. From this data, the locator **704** provides the operator with updated bearing and range information **712**. After further traversal, the operator reaches the load **701**. As can be seen from this example, the present invention does not require the beacon to be stationary during system operation. Thus, the present system provides an advantage over prior location systems that required the beacon to be fixed.

After the load **701** is located, the operator attempts to locate an assembly point **714**, which is located at a different point on the earth. Once again, the locator obtains its own GPS

data based on signals received from GPS satellite transmissions **702**. In addition, it obtains the GPS data for a beacon located at the assembly point **714**. The beacon at the assembly point **714** transmits its GPS data to the locator over a different transmission channel than the first beacon **700** in order to prevent interference (shown as channel "X"). The operator must select the channel corresponding to the transmission channel of the beacon located at assembly point **714**. As previously discussed, the locator calculates and provides the operator with the new bearing and range information **716**. From this information, the operator is able to traverse to the assembly point **714**.

In another embodiment of the present invention, the beacon's GPS data is truncated by the beacon in order to reduce the amount of information that must be transmitted to a cooperative locator. The GPS receiver provides position data in the form of *X*, *Y*, and *Z* coordinates measured in meters from the center of the earth. The position data is provided using 9 significant digits (e.g., 4137958.36). The data compression is achieved by truncating all the axes of the beacon's GPS data. For example, to provide a system that is operational within 10,000 meters, the beacon need not transmit the first three digits of the GPS data. In addition, the system may limit its resolution to 1 meter and therefore the last two significant digits may be truncated. Thus, the beacon may truncate the *X*, *Y*, and *Z* data to four digits (*e.g.*, 4137958.36 is truncated to 7958). At the locator, the first three digits can be reconstituted from the locator's own position. Therefore, in this embodiment, less than half the position data actually needs to be transmitted. It should be further understood that the data may be truncated using other range and resolution requirements. For example, for a range of 100,000 meters with a resolution of one hundred meters, only three digits need to be transmitted (e.g., 4137958.36 is truncated to 379). Notably, truncating the data also adds a degree of security since an unauthorized receiver outside the intended range of the device will be unable to properly reconstruct the true location of the beacon.

This truncation method, however, does not work when the most significant digits of the GPS coordinate data are not the same at the locator and the beacon. Therefore, the locator is further operable to detect when the most significant digits are not the same at the locator and the beacon and compensate for this fact. To see how this can be accomplished, consider a one-dimensional example in which the beacon is located at *X* coordinate 4137958, a locator is positioned 3 km away at *X* coordinate 4140958, and the system operates with a resolution of 1

meter (*i.e.* the last two digits of the X coordinate is truncated). Further, let k be an integer that is not less than twice the range of the system in meters. For example, for the present system to have a range of 3km, k may be selected as equal to 10 km. The beacon decomposes its location X into the sum $X_{base} + X_{scaled}$ where $k > X_{scaled} \geq 0$ and where X_{base} is positive and evenly divisible by k. If $k = 10$ km, then $X_{scaled} = 7958$ meters and $X_{base} = 4130000$ meters. The beacon encodes and transmits the X_{scaled} figure to the locator.

The locator's position (4140958) is similarly decomposed into the sum $X'_{base} + X'_{scaled}$ where $X'_{base} = 4140000$ meters and $X'_{scaled} = 958$ meters. To calculate the distance to the beacon, the locator first adds the base position X'_{base} to the received beacon position, which suggests that the beacon is located at 4147958 meters. However, this location cannot be correct since it would suggest that the beacon is 7000 meters (*i.e.* more than $k/2$ meters) from the locator. Thus, the actual location of the beacon must be 4137958 meters (k meters less than the first figure) because that figure suggests a distance to the beacon of 3000 meters, which is less than $k/2$ meters. This one-dimensional example is intended only as a demonstration of the method. It should be understood, however, that the extension of the present example to three dimensions and other resolutions is well within the ordinary skill in the art. An exemplary version of pseudo code for implementing this data truncation for the X coordinate data is provided below. It should be understood, however, that the same algorithm is applied to the Y and Z coordinate data.

```
/***********************************BEACON**********************************
/

/* Beacon acquires GPS datum. */
      read_dat(X_beacon);

/* Datum truncated to datum modulo scaler. */
      X_scaled = X_beacon % k;
/*************************************************************************
*
Scaler (k) must be a value larger than twice the designed range of the system. The significant
digits of the system is driven by the designed operating range.
**************************************************************************
/
/* Truncated datum X_scaled is encoded and transmitted to Locator, */
      xmit(X_scaled);
```

/***********************************LOCATOR***********************************
/

/* Locator acquires GPS datum. */
read_dat($X_{locator}$);

/* Locator receives beacon datum. */
rcv(X_{beacon_in});

/* Locator truncates copy of datum. */
$X_{scaled} = X_{locator}$ % k;
/**
*
Scalar (k) is identical to beacon scaler.
****
/

/* Locator removes local truncated datum from acquired datum. */
$X_{base} = X_{locator} - X_{scaled}$;

/* Locator adds in received Beacon datum. */
$X_{beacon} = X_{base} + X_{beacon\_in}$;

/* Locator determines delta of data. */
$delta_x = X_{locator} - X_{beacon}$;

/* If $delta_x > k/2$ then X_{beacon} should have been one significant digit above or below $X_{locator}$ */
If ($delta_x > (k/2)$)
$delta_x = delta_x - (k * (delta_x / |delta_x|))$;

/* ($delta_x / |delta_x|$) determines the sign of the error. This compensates for cases when X_{beacon} and $X_{locator}$ have differing significant digits. */

FIG. 8 displays a graph of the GPS accuracy for various GPS locator systems, including the relative locator system of an embodiment of the present invention. The *y*-axis of the graph shows the relative error in meters between a beacon's actual location and the locator's calculated location of the beacon. The *x*-axis shows the probability that the locator will calculate the location of the beacon within the distance between the beacon's actual location and the locator's calculated location of the beacon. As illustrated in FIG. 8, a locator system using a C/A absolute solution has a high probability that the distance between the actual beacon and the calculated location of the beacon is in error. The Y absolute solution, in which no induced S/A errors are introduced, has a much lower probability of error. Finally, despite S/A

induced errors, the C/A relative solution to a beacon of the present invention has a much higher probability that it is accurate than a C/A absolute solution. This accuracy is achieved because both the beacon and locator have the same error introduced when using the same satellites at the beacon and the transmitter to calculate position data. Thus, the error is canceled when the locator determines the direction and range from the locator to the cooperative beacon. Therefore, the present invention provides a significant improvement over prior art systems which require a surveyed base location that transmits the calculated induced S/A random error to the locator.

All of the methods and/or apparatus disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the devices and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the methods and/or apparatus and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit, and scope of the invention. Therefore, all such substitutions and modifications apparent to those skilled in the art are deemed to be within the spirit, scope, and concept of the invention as defined by the appended claims.

CLAIMS:

1. A cooperative location system for use with a Global Positioning System (GPS), which comprises:

a beacon positioned at a first point on the earth and including

a first receiver capable of receiving GPS signals and providing a first set of GPS data representing said first point on the earth, and

a transmitter operable to transmit said first set of GPS data representing said first point on the earth;

a locator positioned at a second point on the earth and including

a second receiver capable of receiving GPS signals and providing a second set of GPS data representing said second point on the earth,

a third receiver capable of receiving said first set of GPS data representing said first point on the earth from said transmitter,

a compass operable to provide a reference direction,

a processor operatively coupled to said second and third receivers, capable of calculating range and direction information of said beacon from said first set of GPS data representing said first point on the earth, said second set of GPS data representing said second point on the earth, and said reference direction.

2. The cooperative location system of claim 1, wherein said transmitter of said beacon transmits using RF signals.

3. The cooperative location system of claim 2, wherein said transmitter of said beacon transmits using VHF signals.

4. The cooperative location system of claim 1, wherein said transmitter of said beacon is operable to transmit truncated GPS data.

5. The cooperative location system of claim 1, wherein:

said beacon is operable to extract coordinate data from said first set of GPS data to form a first set of GPS coordinate data, to truncate said first set of GPS coordinate data to form a first set of truncated GPS coordinate data, and to transmit said first set of truncated GPS coordinate data to said locator, and

wherein said locator is operable to extract coordinate data from said second set of GPS data to form a second set of GPS coordinate data.

6. The cooperative location system of claim 5, wherein said first set of truncated GPS coordinate data is formed by retaining the least significant digits of said first set of GPS coordinate data that are lower in order than the most significant digit of twice a specified maximum range of operation around said beacon.

7. The cooperative location system of claim 6, wherein said locator is operable to determine when said first set of truncated GPS coordinate data differs from the digits of said second set of GPS coordinate data that are greater than or equal in order to the most significant digit of twice said specified maximum range of operation around said beacon.

8. The cooperative location system of claim 1, wherein said compass is an electronic compass.

9. The cooperative location system of claim 1, wherein said first set of GPS data includes GPS satellite identification information.

10. The cooperative location system of claim 9, wherein said locator is operable to display information indicating when said locator and said beacon derive said first and second set of GPS data from an identical set of GPS satellites.

11. A method for determining the location and direction of a beacon located at a first point on the earth, comprising:

receiving a first set of GPS data representing the first point on the earth;

receiving a second set of GPS data representing a second point on the earth;

determining a reference direction from a compass;

calculating range and direction information of the beacon from said first and second set of GPS data representing said first and second points on the earth and said reference direction.

12. The method of claim 11 wherein said first set of GPS data is truncated GPS data.

13. The method of claim 11, further comprising:

extracting from said first and second sets of GPS data a first and second set of GPS coordinate data, and

truncating said first set of GPS coordinate data to form a first set of truncated GPS coordinate data.

14. The method of claim 13, wherein said first set of truncated GPS coordinate data is formed by retaining the least significant digits of said first set of GPS coordinate data that are lower in order than the most significant digit of twice a specified maximum range of operation of the beacon.

15. The method of claim 14, further comprising determining when the digits of said first set of GPS truncated data differs from the digits of said second set of GPS coordinate data that are greater than or equal in order to the most significant digit of twice said specified maximum range of operation of the beacon.

16. The method of claim 11, further comprising displaying when said first and second set of GPS data is derived from the same GPS satellites.

17. A locator for use in a cooperative location system comprising:

a first receiver capable of receiving a first set of GPS data representing the position of a cooperative beacon,

a second receiver capable of receiving GPS signals and providing a second set of GPS data representing the position of the locator,

a compass for providing a reference direction,

a processor operatively coupled to said first and second receivers, capable of calculating range and direction information of said beacon from said first set of GPS data representing the position of said cooperative beacon, said second set of GPS data representing the position of said locator, and said reference direction.

18. The locator of claim 17, wherein said first set of GPS data is truncated GPS data.

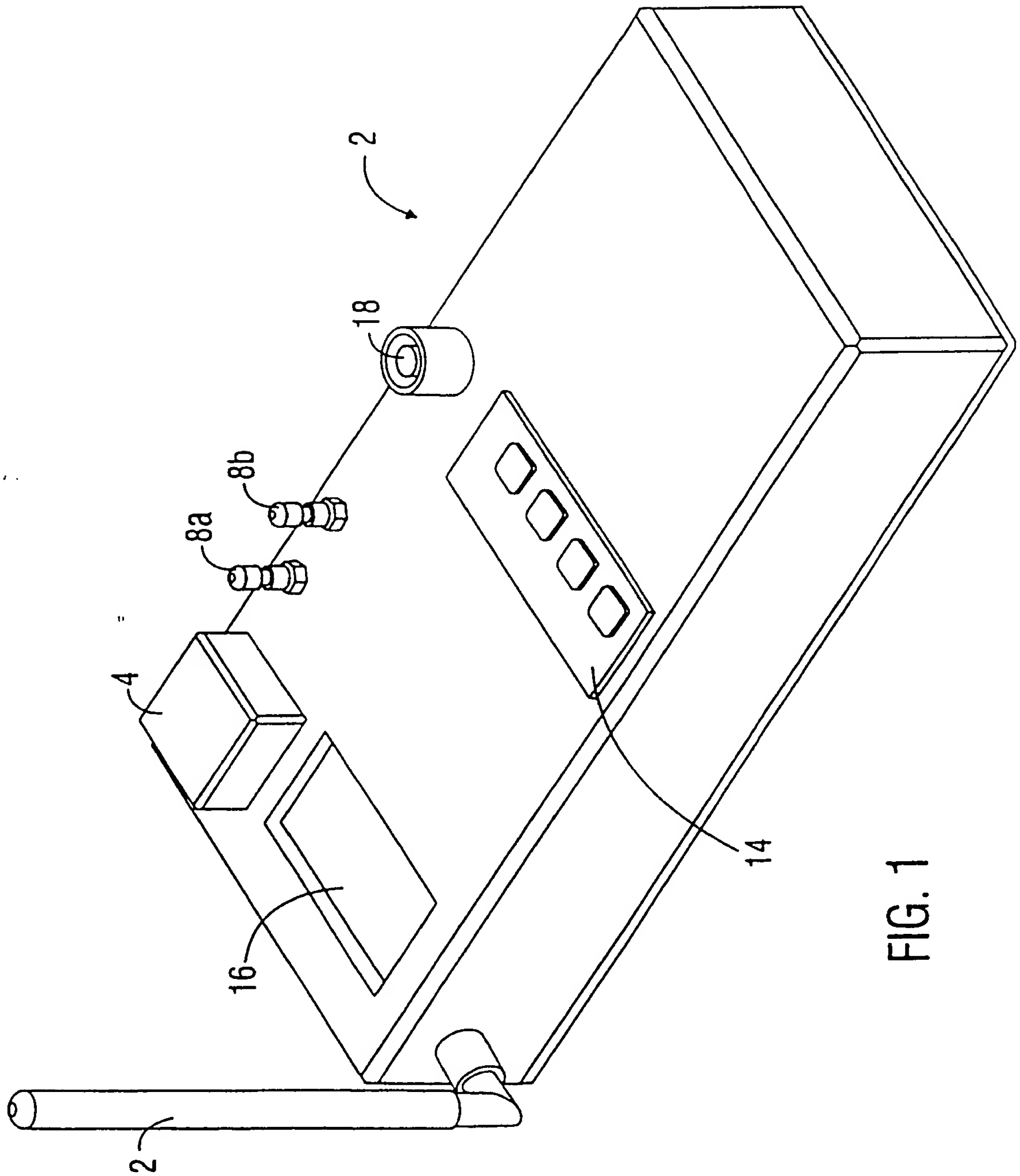


FIG. 1

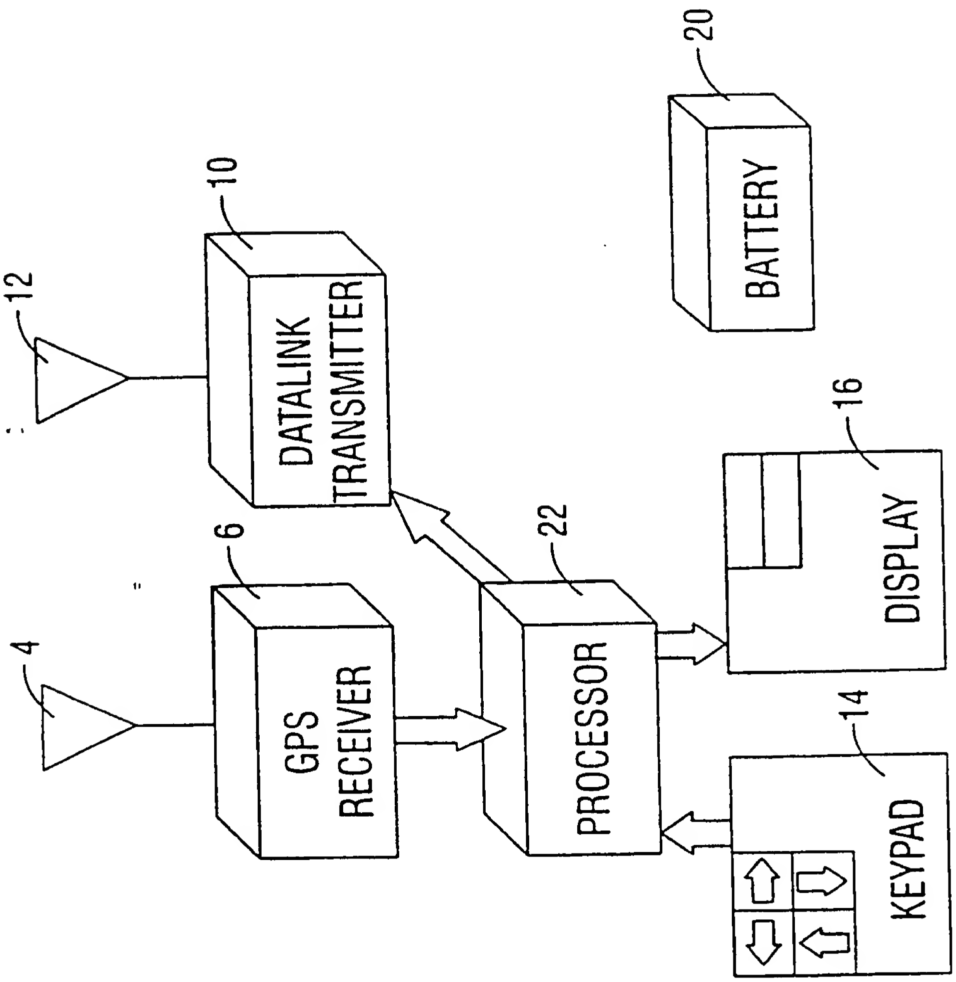

4
6
GPS RECEIVER
12
10
DATALINK TRANSMITTER
22
PROCESSOR
20
BATTERY
16
DISPLAY
14
KEYPAD

FIG. 2

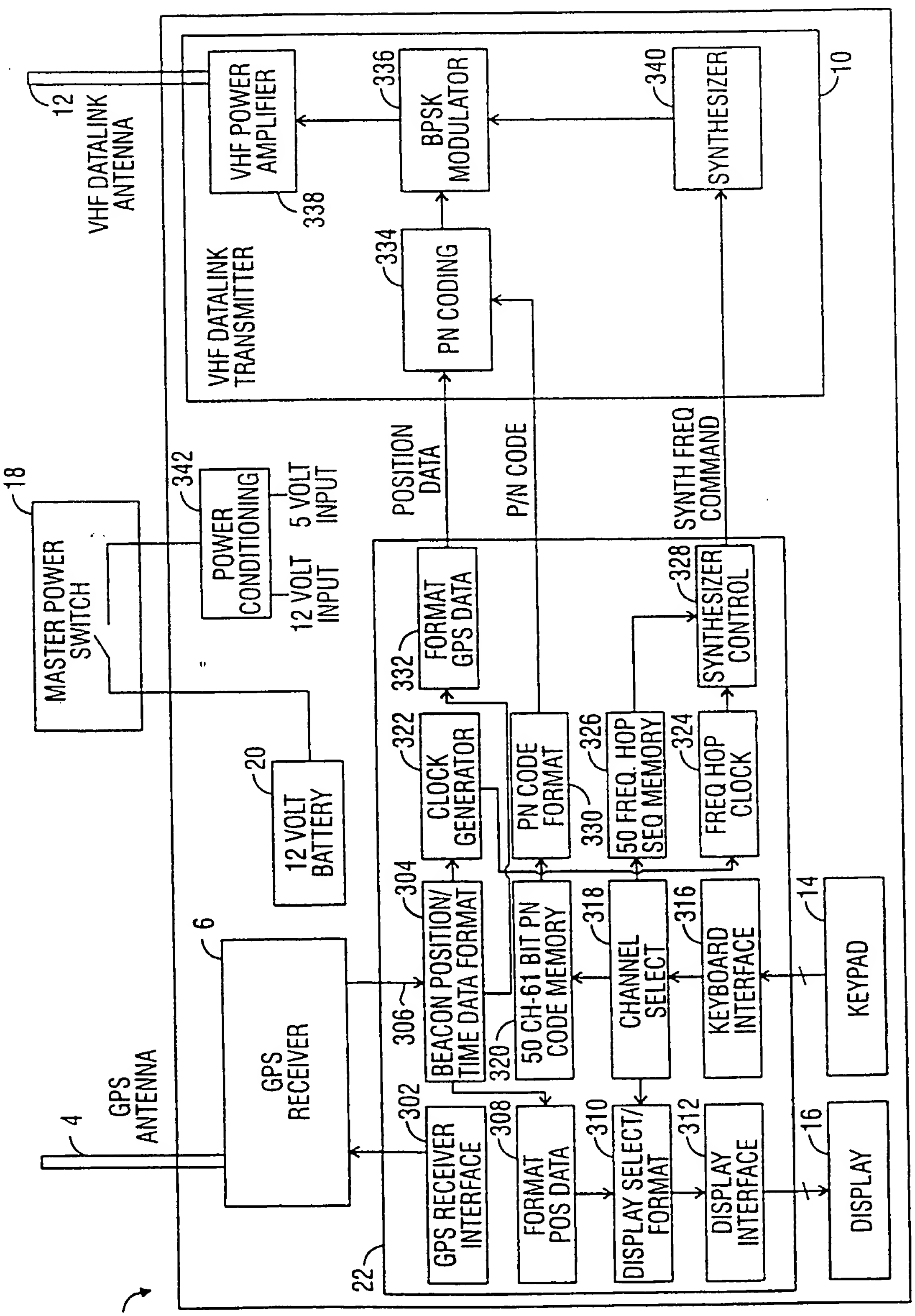

VHF DATALINK ANTENNA
12
VHF POWER AMPLIFIER
338
336
BPSK MODULATOR
340
SYNTHESIZER
10
VHF DATALINK TRANSMITTER
334
PN CODING
POSITION DATA
P/N CODE
SYNTH FREQ COMMAND
18
MASTER POWER SWITCH
342
POWER CONDITIONING
12 VOLT INPUT
5 VOLT INPUT
20
12 VOLT BATTERY
332
FORMAT GPS DATA
328
SYNTHESIZER CONTROL
322
CLOCK GENERATOR
PN CODE FORMAT
326
50 FREQ. HOP SEQ MEMORY
324
FREQ HOP CLOCK
330
6
GPS RECEIVER
304
BEACON POSITION/ TIME DATA FORMAT
306
50 CH-61 BIT PN CODE MEMORY
320
318
CHANNEL SELECT
316
KEYBOARD INTERFACE
14
KEYPAD
4
GPS ANTENNA
302
GPS RECEIVER INTERFACE
308
FORMAT POS DATA
310
DISPLAY SELECT/ FORMAT
312
DISPLAY INTERFACE
16
DISPLAY
22
2

FIG. 3

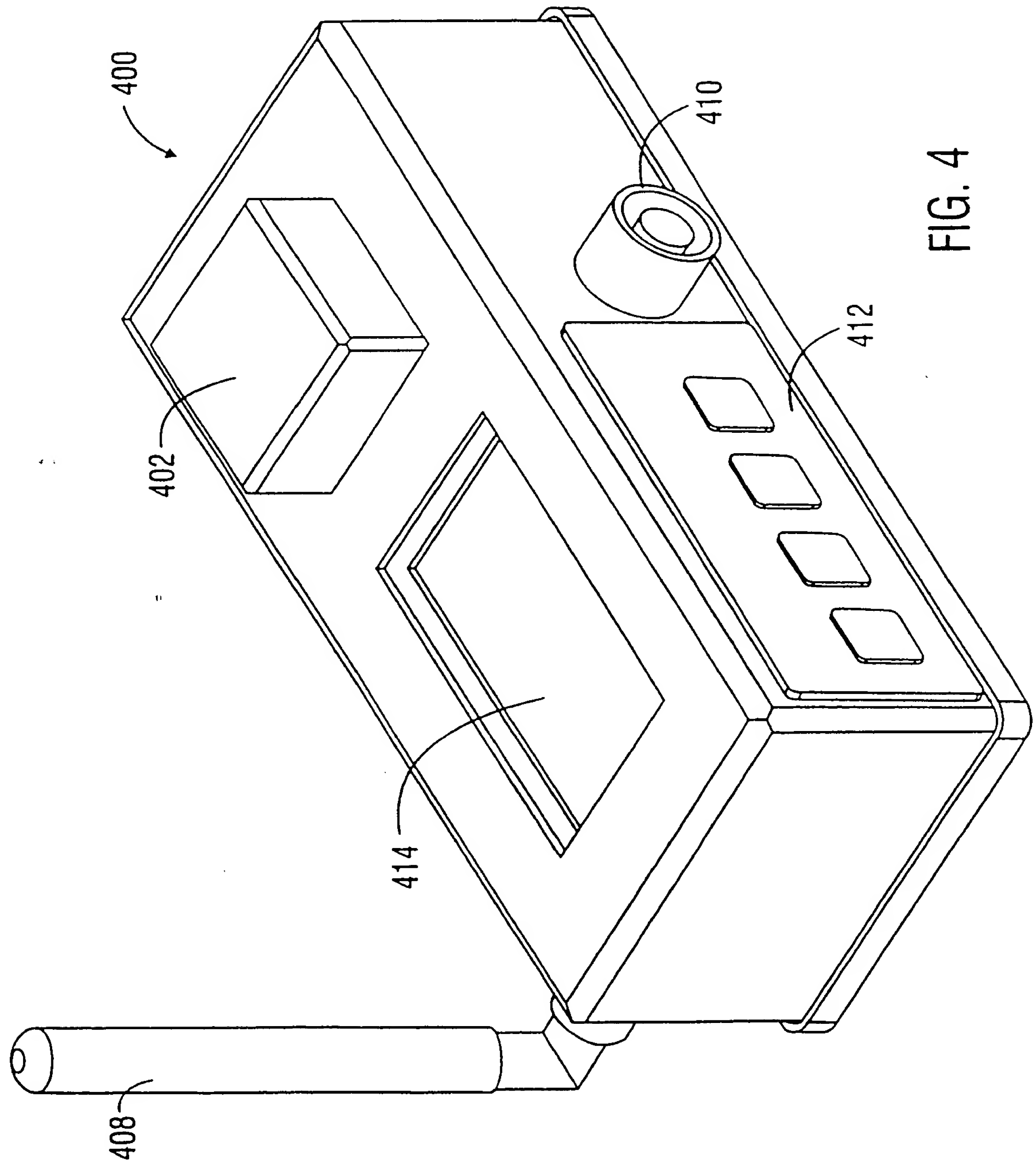


FIG. 4

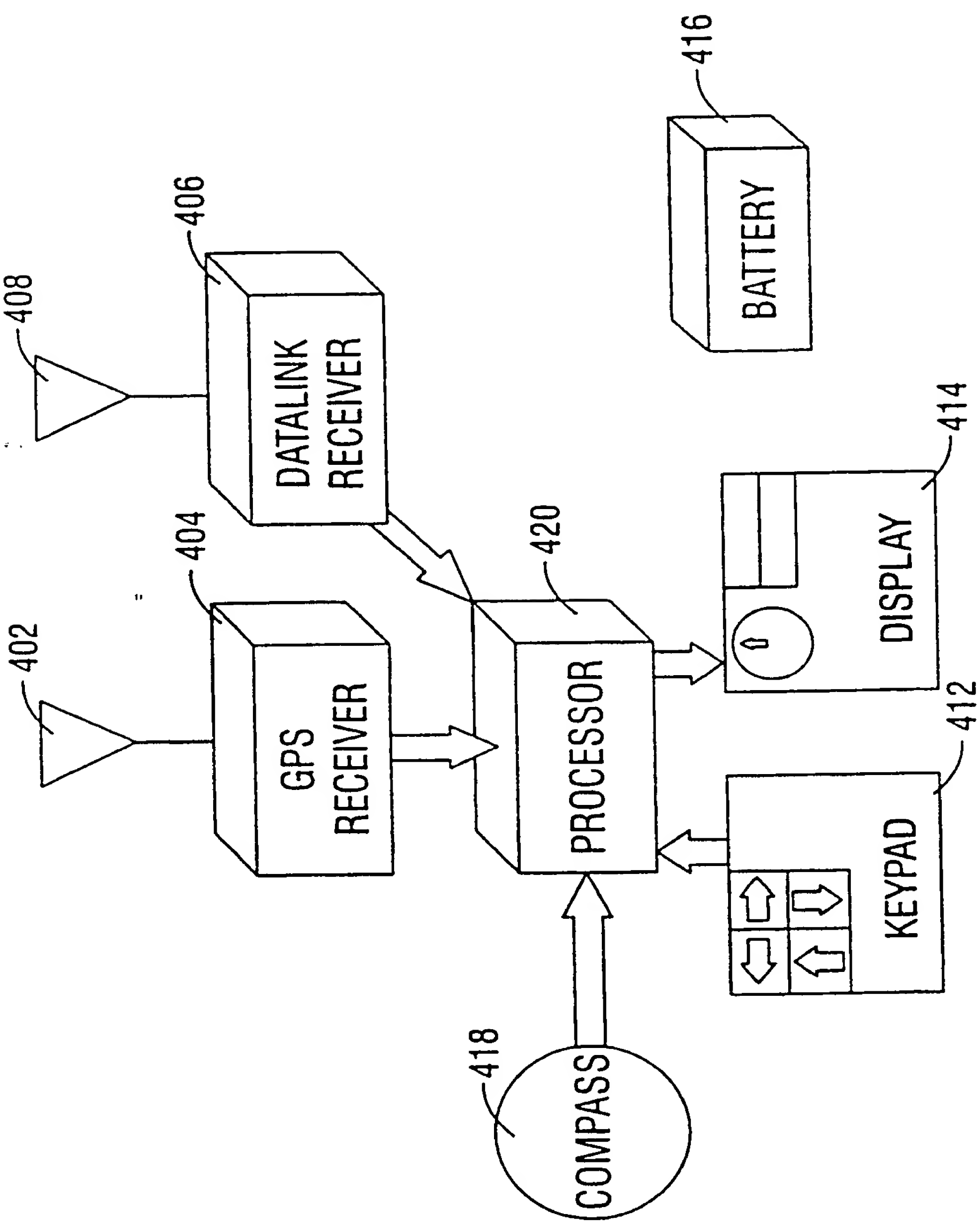
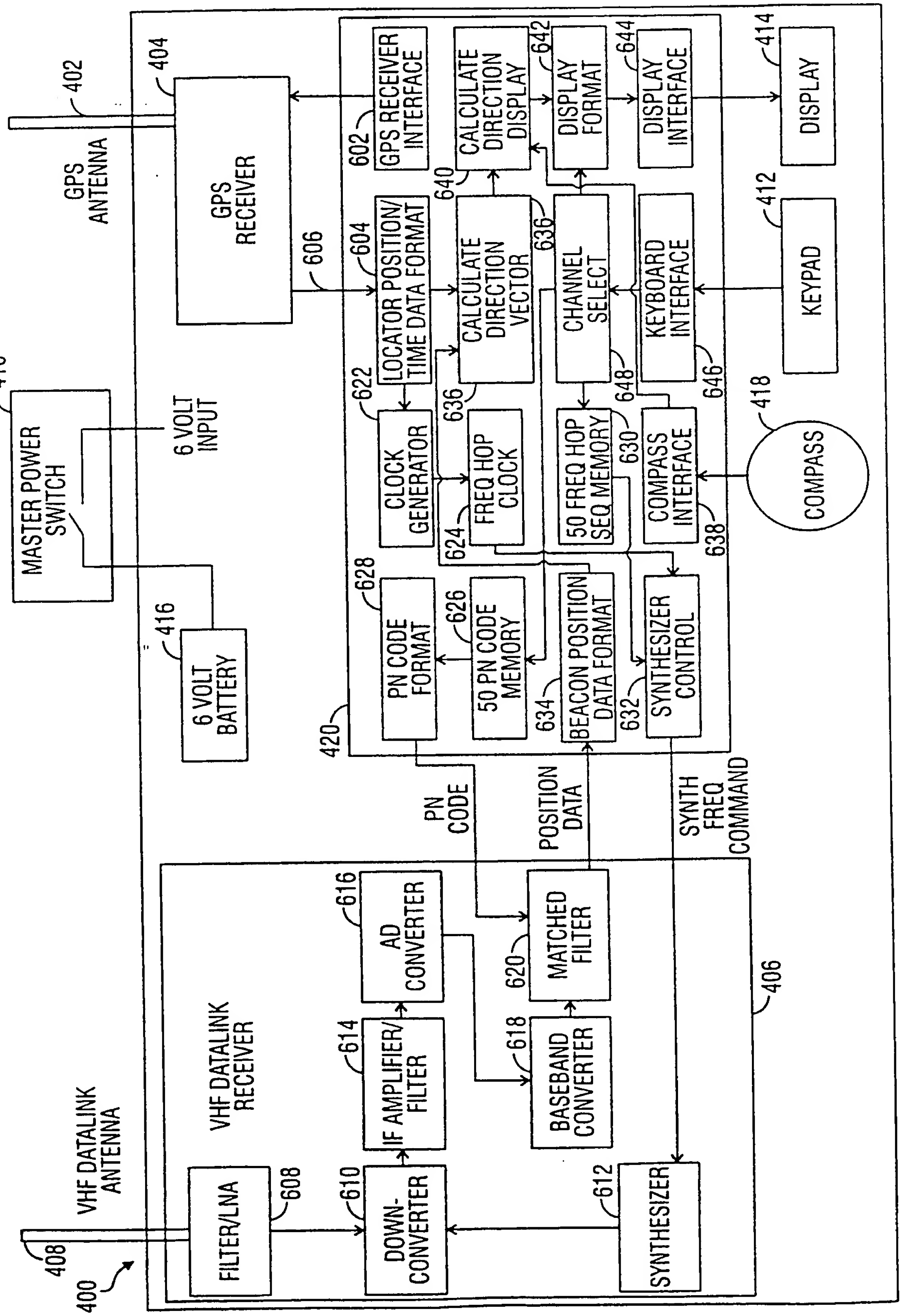

402
404
406
408
416
BATTERY
DATALINK RECEIVER
GPS RECEIVER
420
PROCESSOR
DISPLAY
414
412
KEYPAD
418
COMPASS

FIG. 5



GPS ANTENNA
402
404
GPS RECEIVER
606
602
GPS RECEIVER INTERFACE
604
LOCATOR POSITION/ TIME DATA FORMAT
CALCULATE DIRECTION DISPLAY
640
CALCULATE DIRECTION VECTOR
642
DISPLAY FORMAT
644
DISPLAY INTERFACE
414
DISPLAY
636
CHANNEL SELECT
KEYBOARD INTERFACE
412
KEYPAD
646
648
MASTER POWER SWITCH
410
6 VOLT INPUT
622
CLOCK GENERATOR
FREQ HOP CLOCK
624
50 FREQ HOP SEQ MEMORY
630
COMPASS INTERFACE
638
418
COMPASS
416
6 VOLT BATTERY
628
PN CODE FORMAT
626
50 PN CODE MEMORY
634
BEACON POSITION DATA FORMAT
632
SYNTHESIZER CONTROL
420
PN CODE
POSITION DATA
SYNTH FREQ COMMAND
VHF DATALINK ANTENNA
408
400
VHF DATALINK RECEIVER
FILTER/LNA
608
610
DOWN-CONVERTER
614
IF AMPLIFIER/ FILTER
616
AD CONVERTER
618
BASEBAND CONVERTER
620
MATCHED FILTER
612
SYNTHESIZER
406

FIG. 6

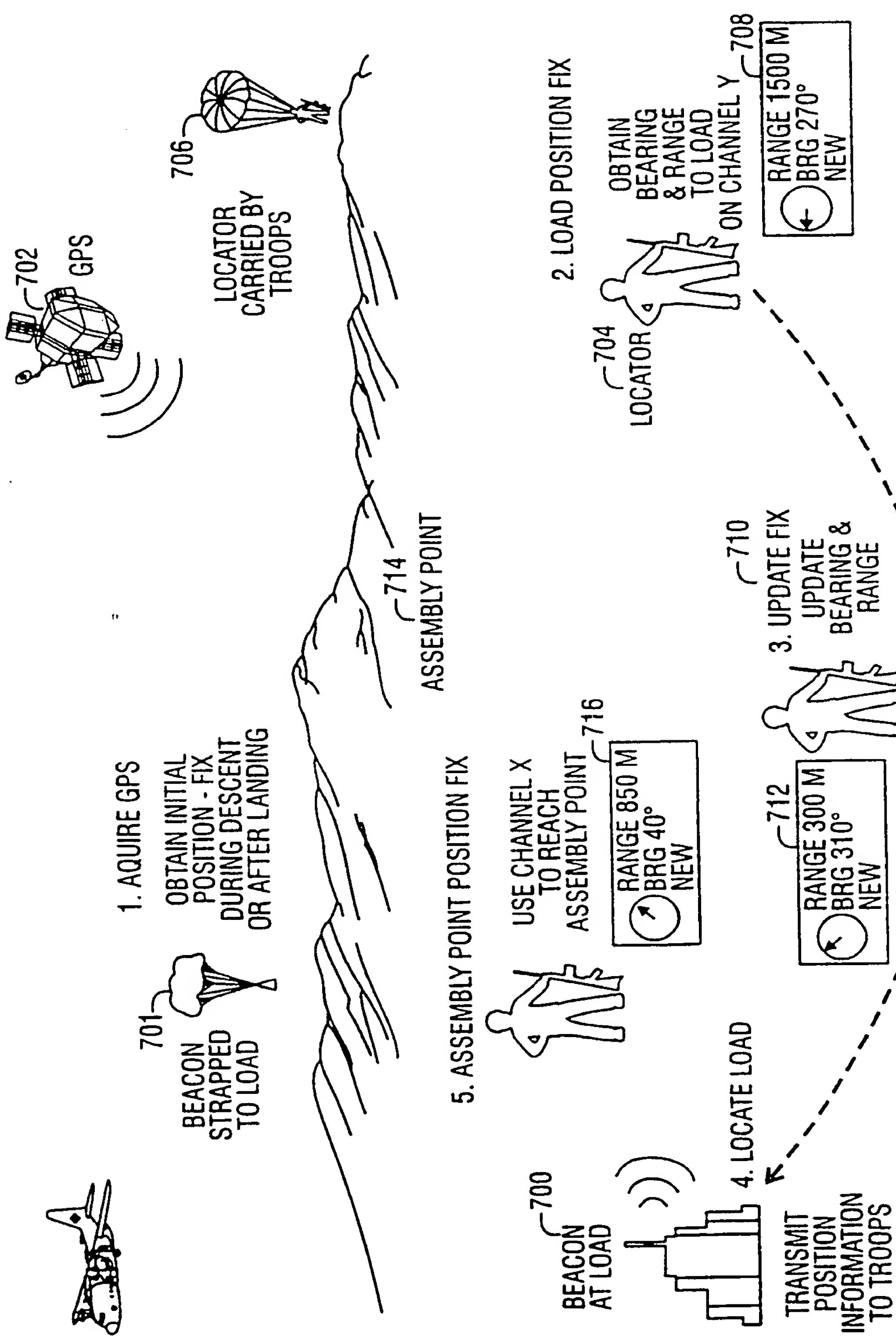

702
GPS
706
LOCATOR CARRIED BY TROOPS
2. LOAD POSITION FIX
OBTAIN BEARING & RANGE TO LOAD ON CHANNEL Y
708
RANGE 1500 M
BRG 270°
NEW
704
LOCATOR
1. AQUIRE GPS
OBTAIN INITIAL POSITION - FIX DURING DESCENT OR AFTER LANDING
701
BEACON STRAPPED TO LOAD
714
ASSEMBLY POINT
710
3. UPDATE FIX
UPDATE BEARING & RANGE
5. ASSEMBLY POINT POSITION FIX
USE CHANNEL X TO REACH ASSEMBLY POINT
716
RANGE 850 M
BRG 40°
NEW
712
RANGE 300 M
BRG 310°
NEW
4. LOCATE LOAD
700
BEACON AT LOAD
TRANSMIT POSITION INFORMATION TO TROOPS

FIG. 7

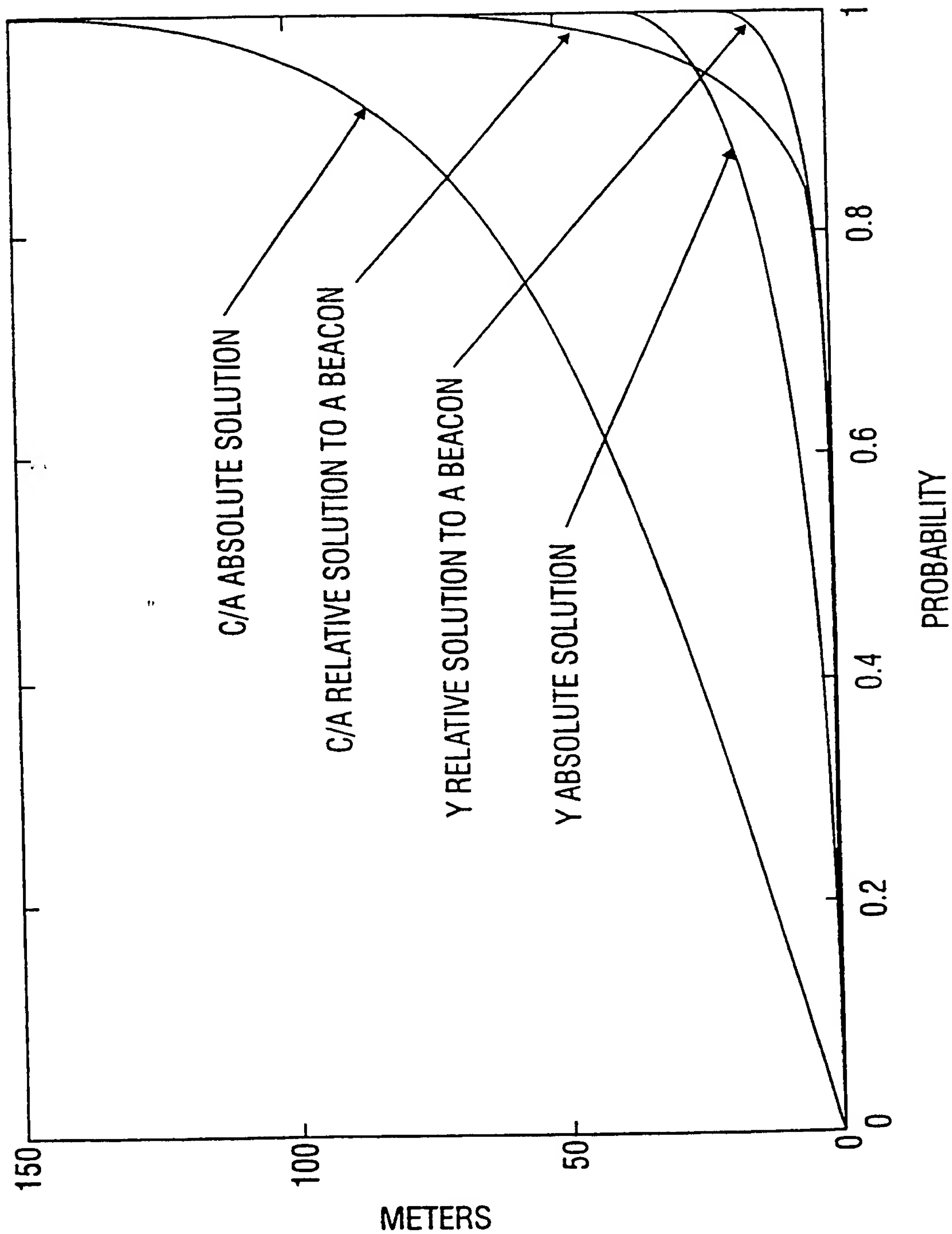

C/A ABSOLUTE SOLUTION
C/A RELATIVE SOLUTION TO A BEACON
Y RELATIVE SOLUTION TO A BEACON
Y ABSOLUTE SOLUTION
METERS
150
100
50
0
PROBABILITY
0
0.2
0.4
0.6
0.8
1

FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/11985

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01S5/14 G01S1/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 502 446 A (DENNINGER VALENTINE L) 26 March 1996	1,2,11, 17
Y	see column 4, line 6 - column 6, line 26; figures 1-3	3-5, 8-10,12, 13,16,18
X	FR 2 735 872 A (THOMSON CSF) 27 December 1996	1-3,11, 17
Y	see page 4, line 1 - page 6, line 21; figures 1,2	4,5, 8-10,12, 13,16,18
Y	WO 96 07110 A (BRITISH TELECOMM) 7 March 1996	3-5,12, 13,18
A	see page 16, line 28 - page 17, line 2	6,7,14, 15

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 October 1998	19/10/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Haffner, R

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/11985

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 574 009 A (TOKYO COSMOS CO LTD ;MIWA HIROHIDE (JP)) 15 December 1993 see column 9, line 13 - line 21 ---	9,10,16
P,X	US 5 702 070 A (WAID JAMES D) 30 December 1997 see column 3, line 59 - column 5, line 60 ---	1,2, 9-11,17
Y	WO 96 14558 A (NAVITRAK INTERNATIONAL CORP ;HILL DAVID C (CA); TREADWELL SIMON C) 17 May 1996 see abstract -----	8

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

Interr nal Application No
PCT/US 98/11985

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5502446 A	26-03-1996	NONE	
FR 2735872 A	27-12-1996	EP 0834084 A	08-04-1998
		WO 9701104 A	09-01-1997
WO 9607110 A	07-03-1996	AU 684228 B	04-12-1997
		AU 3393195 A	22-03-1996
		AU 695816 B	20-08-1998
		AU 5538998 A	23-04-1998
		CA 2198886 A	07-03-1996
		EP 0777863 A	11-06-1997
		EP 0837341 A	22-04-1998
		FI 970848 A	28-02-1997
		JP 10505420 T	26-05-1998
		NO 970940 A	28-02-1997
EP 0574009 A	15-12-1993	JP 9230025 A	05-09-1997
US 5702070 A	30-12-1997	NONE	
WO 9614558 A	17-05-1996	AU 3739695 A	31-05-1996